AN2252
Application note

Zero-voltage switching and emitter-switched bipolar transistor in a 3-phase auxiliary power supply

Introduction

The flyback converter is a popular choice in applications where the required power is normally less than 200W. The main reasons explaining its popularity are its simplicity, low cost and high efficiency for a small number of active components.

In switching converters power loss is caused by power dissipation within the parasitic elements of both passive and active components. Power loss in passive components can be reduced by selecting suitable passive components and carefully designing the transformer. Power loss in active components can be improved by selecting suitable active components and making sure that they are used correctly.

Power loss generated by active components can be divided into two categories:

- conduction loss
- switching loss

The aim of the proposed zero-voltage switching control is to reduce switching loss (in this application, the primary switch turn-on loss). The zero-voltage switching control also greatly reduces the EMI generated by primary switch turn-on.

Conduction loss is generated with the device fully turned-on, by the voltage drop across the conducting device. The proposed use of the Emitter-Switched Bipolar Transistor (ESBT) as the primary switch reduces conduction loss efficiently. Moreover, with its low saturation voltage and fast switching capability compared to an IGBT or a bipolar junction transistor (BJT), the ESBT is well suited for this use. These characteristics are essential in applications where a high breakdown voltage capability is required.

The reference board presented in this Application Note gives a solution of a power supply for 3-phase applications like inverters for induction motors, welding machines, UPS etc. Very commonly in this kind of applications, the neutral line is not available or its use is not allowed, and only phase-to-phase voltage is available. The nominal European phase-to-phase voltage is 400VAC. Taking into account a ±20% tolerance, the rectified input bulk capacitor voltage can reach up to 680VDC. The zero-voltage switching topology requires a reflected flyback voltage equal to the input bulk capacitor voltage. For this reason it is necessary to use a switch which will accept at least 1500V and exhibits a low conduction loss during the ON-time. The high-voltage MOSFET switches rated for this voltage, available on the market today are rather expensive due to their large die size. The ESBT, thanks to its low voltage drop, high speed, square reverse bias safe operating area, smaller die size and lower price is well suited for use as a high-voltage power switch.

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1 Theory of ESBT and quasi-resonant operation

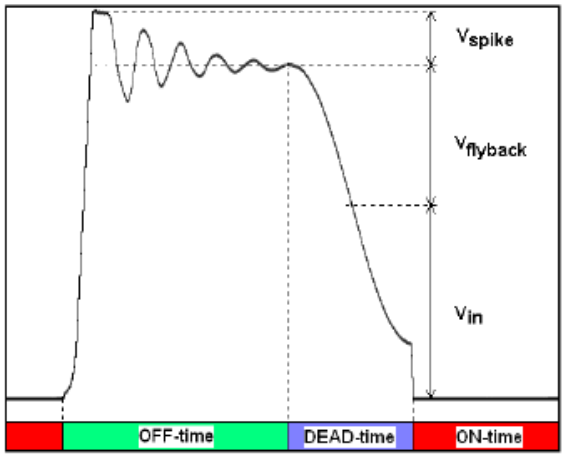
As mentioned in Introduction, the application studied in this Application Note implements zerovoltage switching (ZVS). This principle of operation is also known as quasi-resonant or valley switching.

These names come from the waveform shape of the voltage across the primary side switch during or just before switch turn-on. *Figure 1.* shows the switch voltage, which is the sum of V_{IN}, the DC bulk capacitor voltage, and $V_{flyback}$, the reflected voltage across the primary winding.

The winding voltage depends on the state of the switch and the amount of magnetizing energy stored in the magnetic circuit of the transformer. One switching period can be divided into three basic areas determined by the state of the primary switch and the output diode conduction: the ON time, the OFF time and the DEAD time areas.

- The “ON time” area corresponds to the time during which the primary switch is on and the transformerfs magnetizing inductance stores energy.
- During the “OFF time”, the primary switch is off and the magnetizing inductance energy is discharged through the conducting output diode to the output capacitor. A ringing voltage of amplitude V_{spike} also occurs during this phase. It is generated by the layout-related track inductance and by the leakage inductance created by the imperfect magnetic field coupling between the transformer primary and secondary windings. The ringing voltage amplitude is controlled and limited by a clamp circuit.
- The “DEAD time” starts once all the stored magnetizing inductance energy has been discharged to the output capacitor. It is called “DEAD time” because neither the primary switch nor the output diode is conducting. So there is no energy transfer between the primary side and the secondary side. The primary winding voltage during this phase is resonating and has a cosine waveform starting from a voltage equal to the OFF-time plateau voltage. The DEAD time is used for the initiation of the next switching cycle, only there is no energy conversion, which is why this concept is called QUASI resonant, in comparison with pure resonant converters where the resonance of the primary current or voltage is the means of energy conversion. The voltage waveform has a negative slope and approaches or can even cross zero. The suitable moment to turn the primary switch on again is when the voltage across the primary switch is lowest. The shape of the switch voltage waveform at this point evokes a valley. This is why quasi-resonant or zero-voltage switching is also called valley switching. The resonance frequency during the DEAD time is determined by the magnetizing inductance and parasitic capacitance. The parasitic capacitance consists of the primary switch capacitance, the transformer winding capacitance, the inter-winding capacitance, the capacitances of the diodes located in the secondary, auxiliary and clamp circuits transformed to the primary side. The PCB tracks also generate some parasitic capacitance depending on the layout.

Figure 1. Flyback converter switching cycle - primary switch voltage



The zero-switching operation mode was selected because it has a higher efficiency and produces less EMI. The benefits of using zero-voltage turn-on for the primary switch can be clearly seen by comparing *Figure 2.* and *Figure 4.* The switch voltage obtained with zero-voltage turn-on has a higher waveform and the drain or collector current is lower.

Figure 2. Zero voltage turn-on

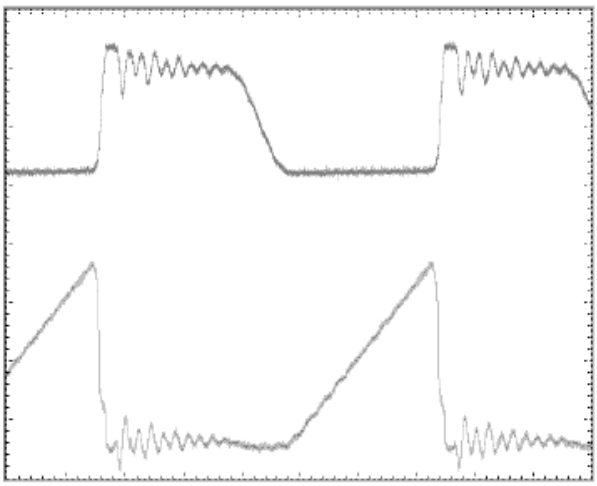
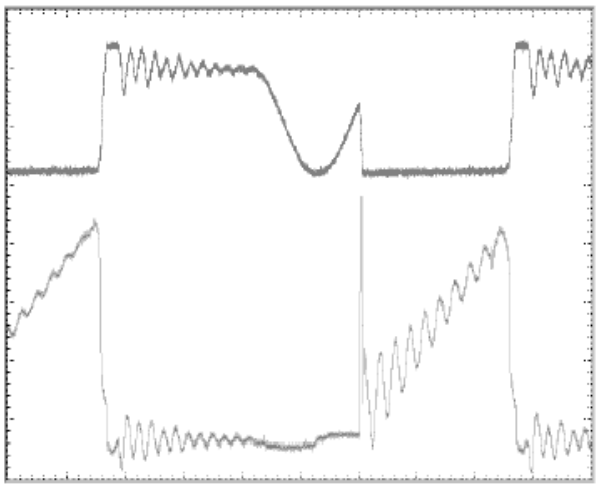


Figure 3. Non zero voltage turn-on

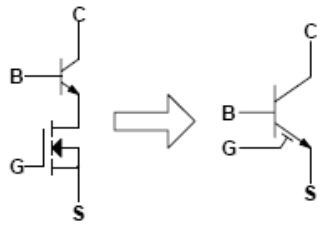


Beside its advantages, the ZVS mode of operation has challenges. The main challenge lies in the voltage rating of the primary switch. One of the conditions required for ZVS is that the voltage across the switch must be able to fall to zero for a certain time during the DEAD time.

This condition can be met by selecting the $V_{flyback}$ voltage so that it is equal to or greater than DC bulk capacitor voltage V_{IN}. The total voltage across the switch can then reach at least twice the maximum V_{IN} voltage. Considering a double maximum value of V_{IN} of 680VDC, a spike voltage V_{spike} of 100V plus a safety margin, a switch rated at a minimum of 1500V is required.

Among the available switches rated for such a high voltage, the high-voltage ESBTs from STMicroelectronics have a low on-state voltage drop like BJTs, a square safe operating area, they are easy to drive and have a switching speed comparable to that of MOSFETs. The ESBT is the cascade configuration of a high-voltage BJT and a low-voltage power MOSFET, as shown in *Figure 5.* This configuration is not brand new and its discrete version is well known. Since STMicroelectronics has a good knowledge and portfolio of high-voltage BJTs and lowvoltage power MOSFETs with very low drain-source on-state resistances (Rds-on), the next step was to integrate and optimize the performance of the two devices by cascading them in a single package to reduce the application complexity, EMI and price, and to increase reliability.

Figure 4. ESBT's internal schematic and symbol



Quasi-resonant controller L6565 controls the ESBT by sending a PWM (Pulse Width Modulation) signal through the gate electrode. The gate electrode drives the internal lowvoltage MOSFET which switches the emitter of the high-voltage BJT to the external pin S (source). This is the reason why the transistor is qualified as "emitter switched". The source pin is usually connected to the application ground.

The base (pin B) of the BJT requires a current bias proportional to the collector current (pin C). This proportional bias may be provided by a current transformer. The current ratio between the base and collector currents is given by the current gain h_{21E} of the internal BJT. The current transformer turns ratio must be adapted to the current gain. An example of a current bias arrangement is given in the *Section 2*. More details concerning the theoretical and practical realizations of the bias circuit and the device operation are beyond the scope of this application note. More details are mentioned in Application Notes AN1699 and AN1889 (see *Section 4*), available from the STMicroelectronics website: www.st.com.

2 Application circuit description

2.1 Operating conditions

Table 1. Input/Output specifications

Description	Value
Input AC voltage range (400 VAC input)	320 - 480VAC
Input DC voltage range (400 VAC input)	450 - 680VDC
Input AC voltage range (230 VAC input)	160 - 240VAC
Input voltage frequency range	50/60Hz
Nominal output voltage	24VDC
Maximum output current	4.3A

2.2 Circuit operation

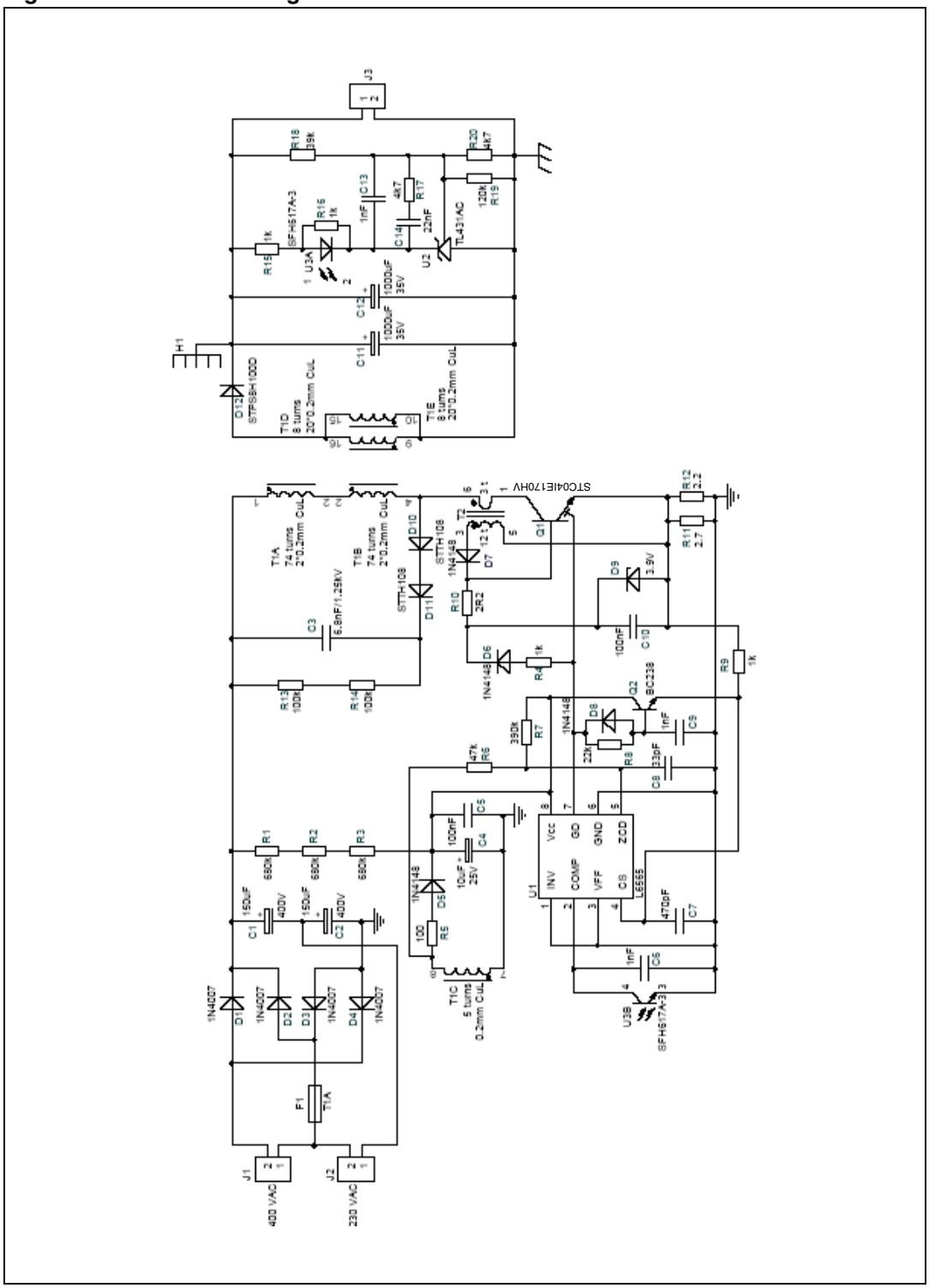
Figure 5. shows the schematic of the power supply. The power supply can be supplied from either an AC or a DC voltage source.

For demonstration purposes in case of an AC supply, power can be supplied through the J2 connector from a single-phase mains of 230VAC. In this case, the input voltage is doubled by a voltage doubler consisting of diodes D2 and D3, and of capacitors C1 and C2.

If the input voltage source is AC with an RMS value above 240VAC, or if it is a DC source, the power supply must be connected through connector J1. In this case diodes D2, D3 and diodes D1, D4 form a bridge rectifier which charges the series-connected capacitors C1 and C2. In the schematic (*Figure 5.*), diodes D1, D2, D3, D4 and capacitors C1, C2 are shown only for demonstration purposes and the converter can be supplied directly from the bus voltage in the application. The control device is a quasi-resonant controller L6565. During normal converter operation it is supplied from the auxiliary winding T1C of power transformer T1 through the one-way rectifier consisting of D5, C4 and C5. Resistor R5 and

capacitors C4 and C5 constitute a low-pass filter whose purpose is to reduce the V_{CC} voltage rise at heavy output loads. At heavy output loads the transformer's parasitic leakage inductance generates ringing on the auxiliary winding voltage.

Figure 5. Schematic diagram



The VCC capacitors are charged during the start-up phase by the permanent current source made up of resistors R1, R2 and R3. Thanks to the very low current consumption of L6565 during the start-up phase, the start-up current is in the order of hundreds of microamperes which significantly reduces the power dissipated in the start-up resistors.

The complete demagnetization of the transformer core is detected by the auxiliary winding voltage crossing zero. Resistor R6 delivers this information to the IC's internal zero crossing detector through pin 5. Resistor R7 shifts the zero-crossing detector threshold towards a value closer to zero for reliable zero crossing during converter start-up or under overload conditions.

Capacitor C8 delays the power switch turn-on to the moment when the collector voltage reaches a valley point. The primary current control circuit consists of current-sense resistors R11, R12 and low-pass filter R9, C7 connected to the CS pin 4 of the control IC.

The primary power switch is the STC04IE170HV. It is an ESBT rated for a maximum current of 5A and collector-to-source voltage of 1500V. The gate of the ESBT is driven directly by the internal gate driver of U1 through pin 7. The ESBT also requires a bias current for the base of the internal BJT. It is provided by current transformer T2 through the diode D7. During the storage time, the collector current flows through the B-C junction for the time required by the junction to recover from conduction. The collector current flows then through capacitor C10 which stores the energy that will generate the initial base current spike necessary for the next switching cycle. The value of this current spike is determined by the voltage across capacitor C10 (which is limited by Zener diode D9), by resistor R10 and by the resistance of the B-E junction of the internal BJT of the ESBT. Diode D6 and resistor R4 provide the bias current required to precharge C10 during the first switching cycle and properly start the converter operation.

Since the current transformer operation may be affected by core saturation when the voltsecond product exceeds the limit, a protection circuit consisting of R8, C9, D8 and Q2 is inserted in the current-sense path. This circuit is a timer which watches the maximum ON time. If the latter goes beyond a certain limit, the current-sense voltage is suddenly increased to its maximum threshold, thus stopping the gate driver and turning off the ESBT through the gate. Without this circuit, the current transformer core saturation would cause the ESBT to be unsafely turned off whenever there is a lack of base current. This condition may happen in case of an undervoltage at the input, for instance if a mains voltage drop occurs or the power supply is unplugged. As a consequence, the ON-time would be increased above the specified current transformer volt-second product limit.

Clamp circuit D10, D11, C3, R13 and R14 protects the ESBT switch from the voltage spikes induced by the transformer leakage inductance.

The output voltage is controlled by an opto-isolated feedback loop consisting of U2, voltage divider R18, R19, R20 and frequency response compensation components R17, C13 and C14. Since most of the voltage stress was moved (by the increased flyback voltage provided by an appropriate transformer's turns ratio) to the primary side, a 100V Schottky diode can be used as a rectifier on the secondary side even if the nominal output voltage is 24V. This is one of the advantages of using the quasi-resonant mode, which further helps decrease the output rectifier loss and increases the overall converter power efficiency.

2.2.1 Bill of materials

The list of components required to build the demonstration board is shown in *Table 2*. Most of the used active components are available from STMicroelectronics. Thanks to the outstanding performance of the ESBT, the switch does not require any heat sink for this

quasi-resonant application delivering a 100W output power. Both inductive components are supplied by VOGT Electronic Components GmbH.

Table 2. Bill of materials

Reference	Qty	Value	Description
C1,C2	2	150µF	Electrolytic capacitor, EPCOS, LL, B43505-A9157-M, 400V
C3	1	6.8nF/1250V	Foil capacitor, EPCOS, B32652A7682J
C4	1	10µF	Electrolytic capacitor, 25V
C5	2	100nF	Ceramic capacitor, 50V, –55 to 125°C
C10	1	100nF/100V	Stacked film polyester capacitor, EPCOS, B32560J1104J
C6, C9, C13	3	1nF	Ceramic capacitor, 50V, –55 to 125°C
C7	1	470pF	Ceramic capacitor, 50V, –55 to 125°C
C8	1	33pF	Ceramic capacitor, 50V, –55 to 125°C
C11, C12	2	1000µF/35V	Electrolytic capacitor, Panasonic EEUFC1V102, Nichicon UPM1V102MHH6
C14	1	22nF	Ceramic capacitor, 50V, –55 to 125°C
D1, D2, D3, D4	4	1N4007	General purpose rectifier, 1000V, 1A, DO-41
D5, D6, D7, D8	4	1N4148	Diode, 75V, 0.15A, DO-35
D9	1	BZX85V3.9	Diode, zener, 3.9V, 1.3W, DO-41
D10, D11	2	STTH108	STMicroelectronics, diode, high voltage ultrafast, 800V, 1A, DO-41
D12	1	STPS8H100D	STMicroelectronics, diode, high voltage power schottky, 100V, 8A, TO-220AC
F1	1	T1A	Fuse, radial, SCHURTER, slow, 1A, 250VAC
H1	1	6099B	Heatsink, AAVID THERMALOY, 6099B, 531102b02500, Rthjc = 11°C/W
Q1	1	STC04IE170HV	STMicroelectronics, Emitter Switched Bipolar Transistor, 4A, 1700V, TO-247 4 leads
Q2	1	BC547B	STMicroelectronics, small signal 100mA, 330mW,TO-92, 150°C
R1, R2, R3	3	680k	Resistor, size 0204, metal film, 250V, 0.185W, 1%
R4, R9, R15, R16	4	1kΩ	Resistor, size 0204, metal film, 250V, 0.185W, 1%
R5	1	100	Resistor, size 0204, metal film, 250V, 0.185W, 1%
R6	1	47kΩ	Resistor, size 0204, metal film, 250V, 0.185W, 1%
R7	1	390kΩ	Resistor, size 0204, metal film, 250V, 0.185W, 1%
R8	1	22kΩ	Resistor, size 0204, metal film, 250V, 0.185W, 1%
R10	1	2R2	Resistor, size 0207, metal film, 350V, 0.6W, 1%
R11	1	2.7	Resistor, size 0207, metal film, 350V, 0.6W, 1%
R12	1	2.2	Resistor, size 0207, metal film, 350V, 0.6W, 1%

Table 2. Bill of materials

Reference	Qty	Value	Description
R13, R14	2	82kΩ	Resistor, size 0414, metal film, 500V, 2W, 5%
R17, R20	2	4,7kΩ	Resistor, size 0204, metal film, 250V, 0.185W, 1%
R18	1	39kΩ	Resistor, size 0204, metal film, 250V, 0.185W, 1%
R19	1	120kΩ	Resistor, size 0204, metal film, 250V, 0.185W, 1%
T1	1	SL 040 923 11 03	VOGT-electronic, Power transformer, ETD39, N67
T2	1	SL 040 903 21 02	VOGT-electronic, Current transformer, RM13*7*4.5, Fi 340
U1	1	L6565	STMicroelectronics, quasi-resonant SMPS controller, DIP-8
U2	1	TL431AI	STMicroelectronics, shunt Reference, 2.5V, 1 to 100mA, 2%, TO-91, –40 to 105°C
U3	1	PC817	optocoupler, SHARP, Viso = 5kV, CTR = 50..600% at IF = 5mA, DIP-4

2.2.2 Transformer design

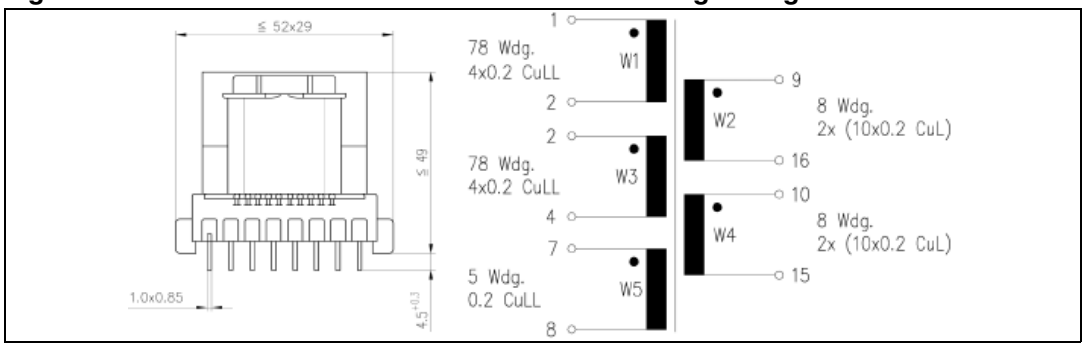
The initial power transformer specification is as follows:

- Minimum input voltage 320VAC = 450VDC
- Minimum switching frequency at full load and minimum input voltage 50kHz
- Reflected flyback voltage 500V
- Converter efficiency at full load and minimum input voltage 90%

The initial power transformer design was further optimized by VOGT Electronic Components GmbH to cope with such a high voltage. Special attention was paid to guarantee VDE distances by padding the winding ends.

To improve magnetic coupling, not only the primary winding but also the secondary was split. The two primary windings so obtained have half the total number of turns each and are connected in series while the two secondary windings have the nominal number of turns and are connected in parallel. The windings are laid out as follows starting from the winding nearest the core: W1 (Primary 1), W2 (Secondary 1), W3 (Primary 2), W4 (Secondary 2) and W5 (Auxiliary). The transformer is designed so as to comply with the EN60950 safety standard for CE certification. If the transformer must be compliant with the UL standard – on the flammability of isolation material – whose compliance is mandatory for applications implemented in the USA, then some modifications are required. The transformer's physical appearance, dimensions and winding arrangement are shown in *Figure 6.*

Figure 6. Power transformer dimensions and winding arrangement



The basic parameters of the power transformer's ferrite core selected from VOGT's ferrite materials and shapes are shown in *Table 3.* The gap size was optimized to meet the current and inductance requirements necessary to provide the nominal output power over the whole input voltage range.

Table 3. Power transformer core parameters

Shape	ETD39
Material	Mf 198
Inductance Factor A_L[nH]	132

An overview of the major parameters for each winding can be found in *Table 4.* Because of the discontinuous conduction flyback, the winding current has only an AC component, and so care was taken of minimizing the eddy current loss. For this reason the primary and secondary windings are made of Litz wire.

Table 4. Power transformer winding parameters

Order	Start Pin	End Pin	No. of turns	Wire diameter [mm]	Wire material	Inductance [H]
1	1	2	78	4 × 0.2	CuLL	803×10^{-6}
2	9	16	8	20 × 0.2	CuLL	8.4×10^{-6}
3	2	4	78	4 × 0.2	CuLL	803×10^{-6}
4	10	15	8	20 × 0.2	CuLL	8.4×10^{-6}
5	7	8	5	0.2	CuLL	3.3×10^{-6}

As was already mentioned, the ESBT requires a proportional base drive to operate. This function is provided by current transformer T2. The basic parameters of the current transformer's ferrite core selected from VOGT's ferrite materials and shapes are given in *Table 5.* The physical appearance, dimensions and winding arrangement of the current transformer are shown in *Figure 7.*

Figure 7. Current transformer dimensions and winding arrangement

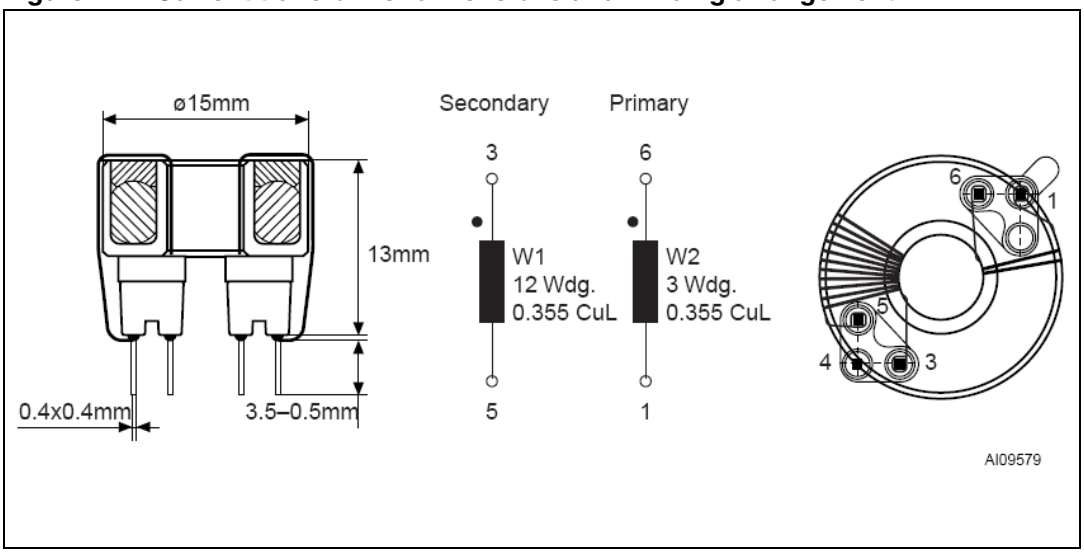


Table 5. Current transformer core parameters

Description	Value
Shape	R13×7×4.5
Material	Fi 340
Inductance Factor A_L [nH]	2200

The number of turns of primary winding W2 was optimized so as to achieve the turns ratio W2/ W1 at which the current transformer follows the current gain of the ESBT and thus provides proportional base current bias for the ESBT over the whole specified input voltage range and output load range. An overview of the major parameters for each winding is given in *Table 6.*

Table 6. Current transformer winding parameters

Start Pin	End Pin	No. of turns	Wire diameter [mm]	Wire material	Inductance [H]
3	5	12	0.355	CuLL	313×10^{-6}
6	1	3	0.355	CuLL	19.6×10^{-6}

2.3 PCB Layout

The PCB is designed as a single-sided board made of FR-4 material with a 70µm copper plating, solder and silk screen mask. The assembled board contains only throughhole components. The outline dimensions are 139 x 61mm. The top side of the assembly can be seen in *Figure 8.*

Figure 8. Assembly schematic

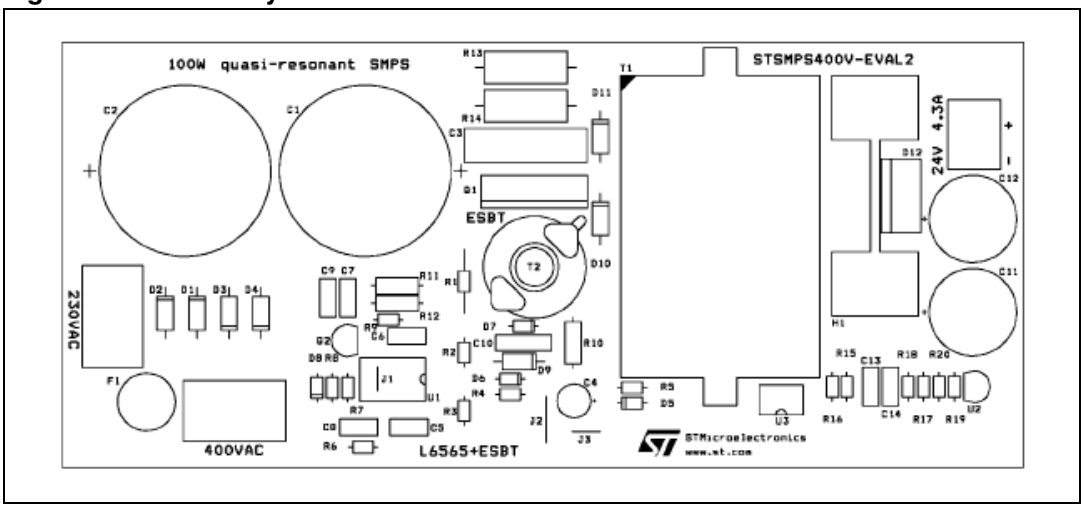


Figure 9. represents the PCB layout of the copper connections. The holes for through hole components are not shown.

Figure 9. PCB layout

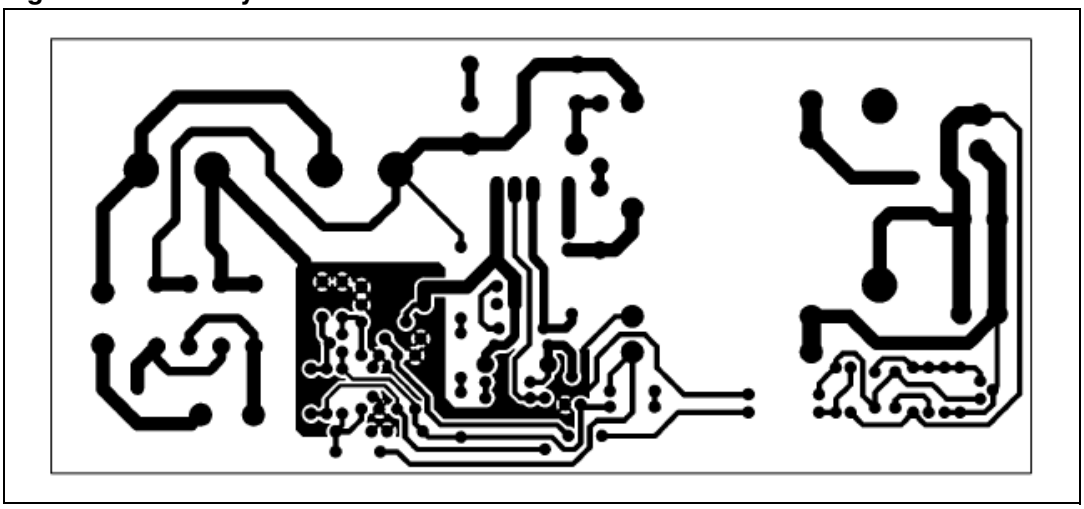


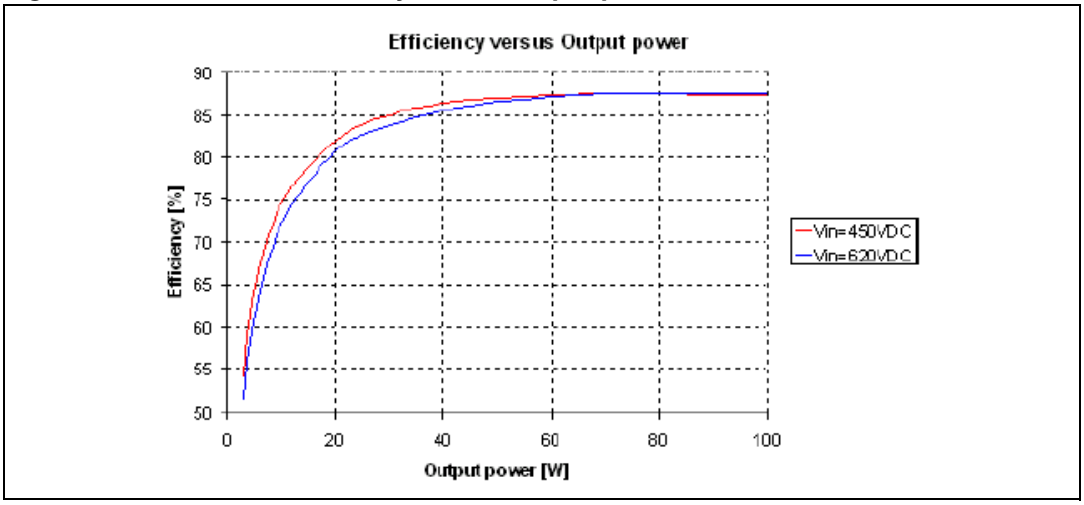
Figure 10. shows the converter.

Figure 10. Picture of the converter

2.3.1 Evaluation and measurements

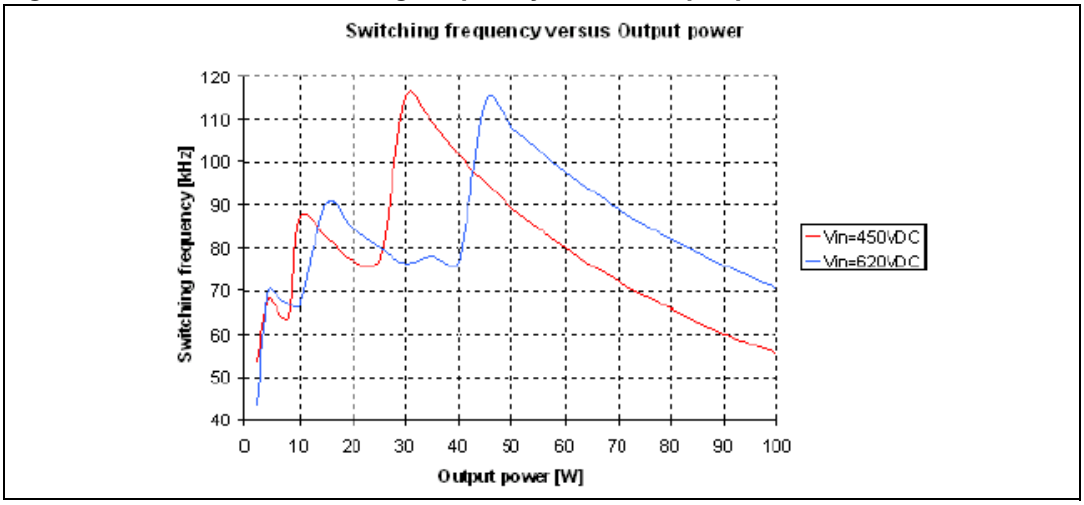
The converter was specially designed to have a high power efficiency. *Figure 11.* shows that the converter's output efficiency depends on the input voltage (two marginal values are taken as example). Since the flyback voltage is not higher than the maximum input voltage, for some values of the input voltage the conditions under which the converter operates in ZVS mode are not met and the primary switch turn-on is no longer lossless. This is clearly seen in *Figure 11.*, where there is a difference in efficiency according to Vin in the medium and low output power regions. At high output powers, however, the primary switch conduction loss prevail over the turn-on loss.

Figure 11. Converter efficiency versus output power



The main characteristic of the ZVS control used with the L6565 is that the switching frequency changes with the load and input voltage. The L6565 has a built-in OFF-time control block which increases the DEAD time by skipping the valley of the collector voltage as soon as the OFF time overreaches the internal threshold value. *Figure 12.* demonstrates the function of this block and shows that the maximum switching frequency is kept below 120kHz and that, at very low load currents the switching frequency has a value similar to that at full load. This has a positive impact on the switching loss under light load conditions. Comparatively for a ZVS control with no valley skipping function, the switching frequency rises dramatically and has a significant impact on the switching loss.

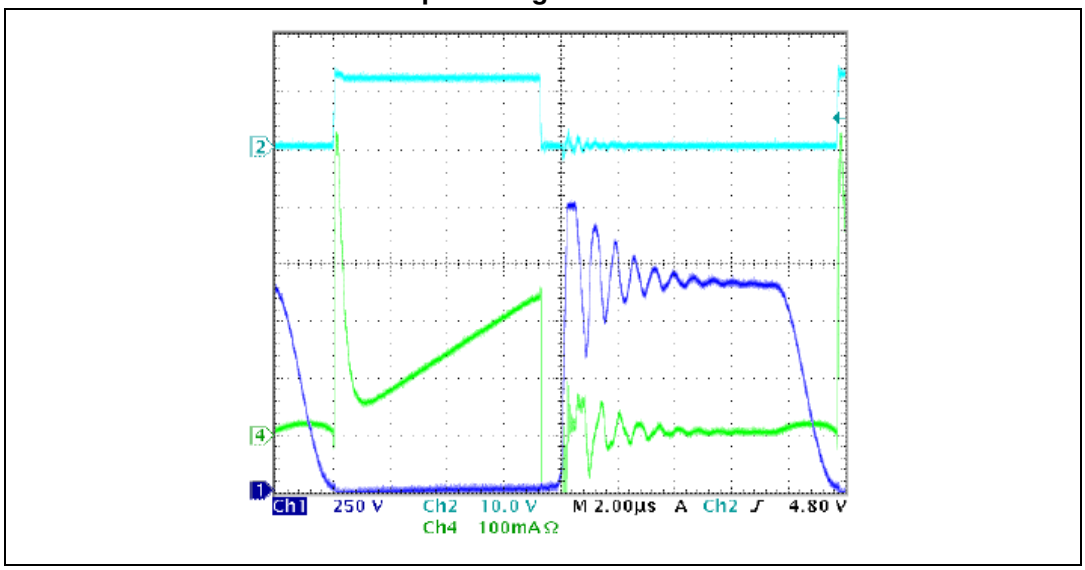
Figure 12. Converter switching frequency versus output power



Detailed views of waveforms under different operating conditions are shown in *Figure 13.*, *Figure 14.*, *Figure 15.* and *Figure 16.*. *Figure 13.* shows the switch collector voltage, gate voltage and base current stored at minimum input voltage and maximum output load. Zero-voltage turn-on on the collector voltage occurs when the gate voltage goes High. The oscilloscope waveform of the base current shows the initial peak provided by capacitor C10, followed by the current ramp supplied by the current transformer. Since more than one waveform is shown, the base current is not at a scale that makes it possible to also show the

full negative current that flows during the storage time. Only part of it can be seen. The storage time estimated from *Figure 13.* is of about 800ns.

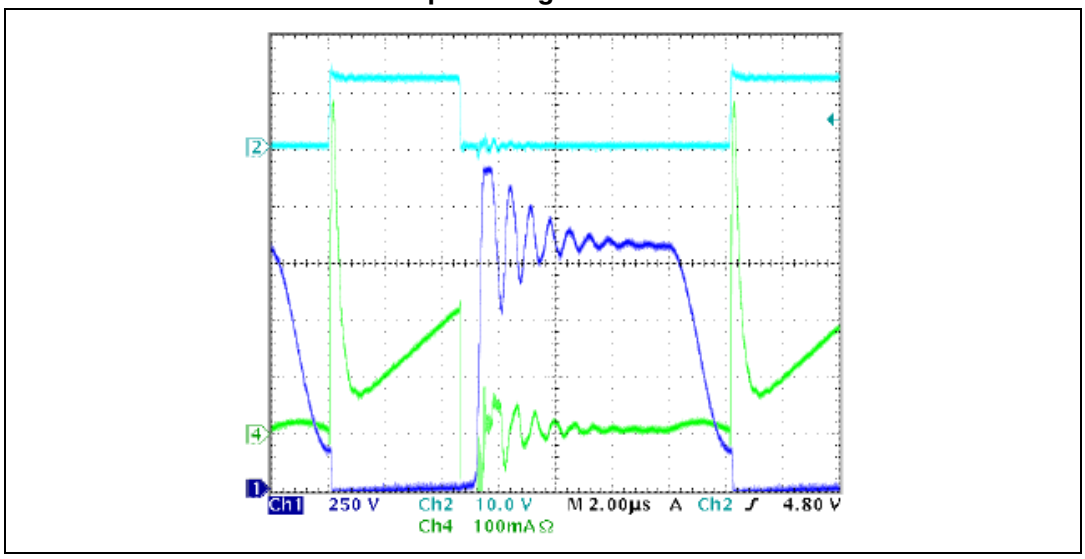
Figure 13. Primary switch collector voltage, gate voltage and base current at full load and minimum input voltage



Note: Channel 1 shows the switch collector voltage (dark blue), channel 2 shows the gate voltage (light blue) and channel 4 shows the base current (green).

Figure 14. shows the same waveforms as *Figure 13.* but under maximum input voltage conditions. Since the flyback voltage is lower than the input voltage, the switch turn-on does not occur at zero voltage as can be seen from the collector voltage. The storage time remains the same.

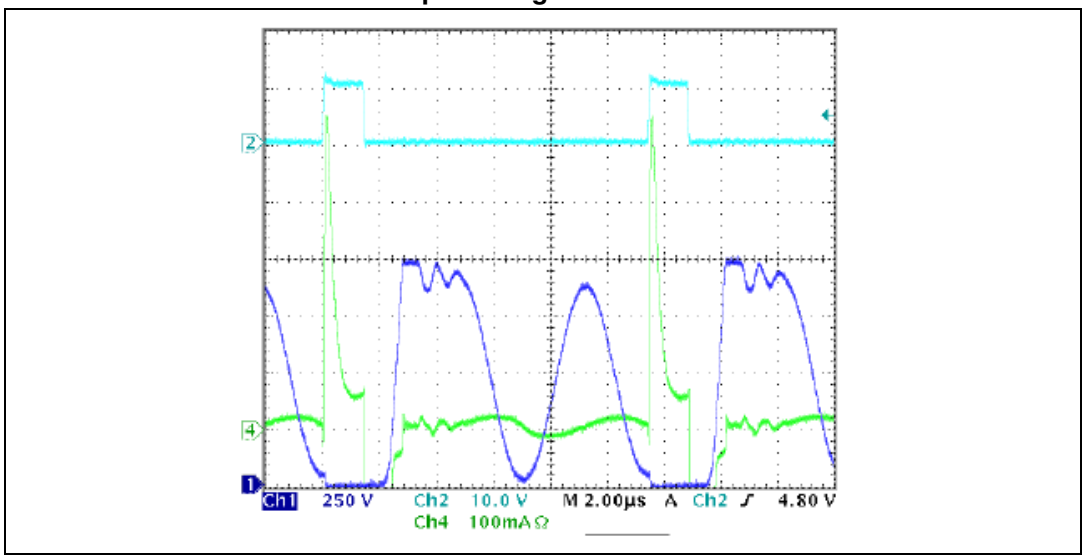
Figure 14. Primary switch collector voltage, gate voltage and base current at full load and maximum input voltage



Note: Channel 1 shows the switch collector voltage (dark blue), channel 2 shows the gate voltage (light blue) and channel 4 shows the base current (green).

Figure 15. shows the same waveforms as *Figure 13.* but at 10% of the specified load. The storage time is the same as for full load: about 800ns. This proves the good design and operation of the current transformer that maintains a constant storage time for different loads and input voltages. *Figure 13.*, *Figure 14.* and *Figure 15.* also highlight the valley-skipping function of the control IC which helps keep the switching frequency within a reasonable range.

Figure 15. Primary switch collector voltage, gate voltage and base current at 10% load and minimum input voltage



Note: Channel 1 shows the switch collector voltage (dark blue), channel 2 shows the gate voltage (light blue) and channel 4 shows the base current (green).

Figure 16. shows that the storage time remains stable even under maximum input voltage conditions.

Figure 16. Primary switch collector voltage, gate voltage and base current at 10% load and maximum input voltage

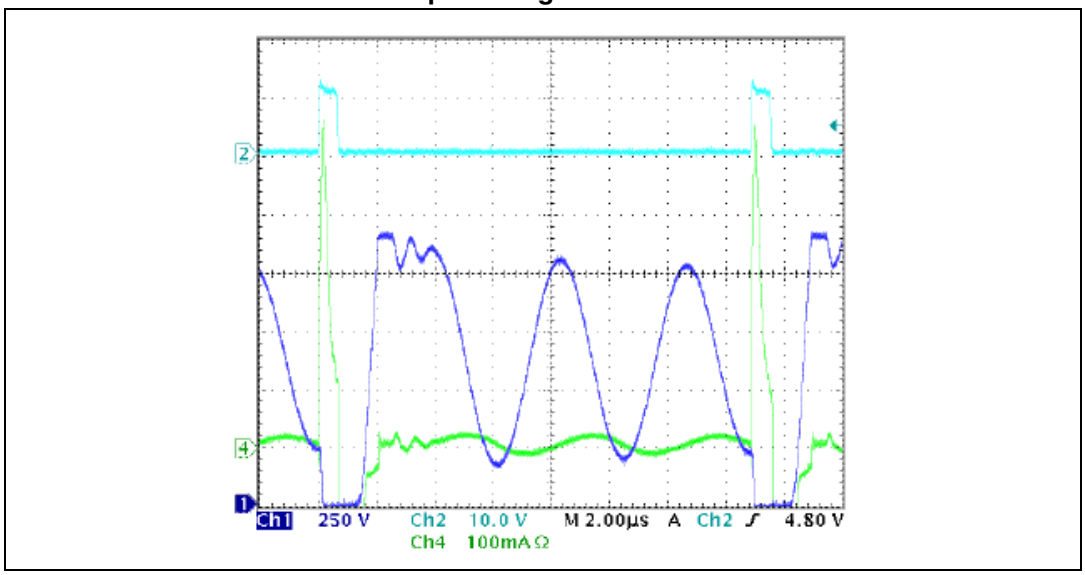


Figure 17. shows the principle of the emitter-switching operation of the ESBT. During the turn-off time the BJT enters the storage time area which can be identified by a negative base current. The amplitude of the base current during the storage time is equal to the actual collector current just before gate turn-off. The base-emitter junction is not conducting and all the collector current flows through the collector-base junction. This process is similar to the reverse recovery of a standard diode. Since the recovery current is high, the storage time is very short. The storage time can be easily read from *Figure 17.* and its value is of about 800ns. Since the baseemitter junction is not conducting, current crowding and hot-spot effects are greatly reduced, which gives rise to an excellent square Reverse Bias Safe Operating Area (RBSOAR) similar to the Safe Operating Area (SOAR) of power MOSFETS.

Figure 17. Detailed view of the primary switch base current

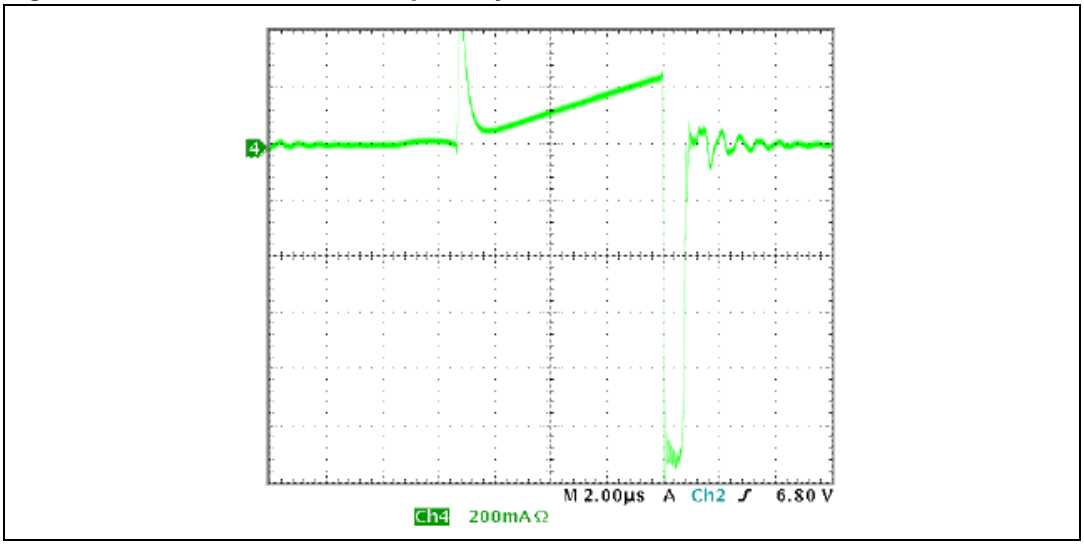
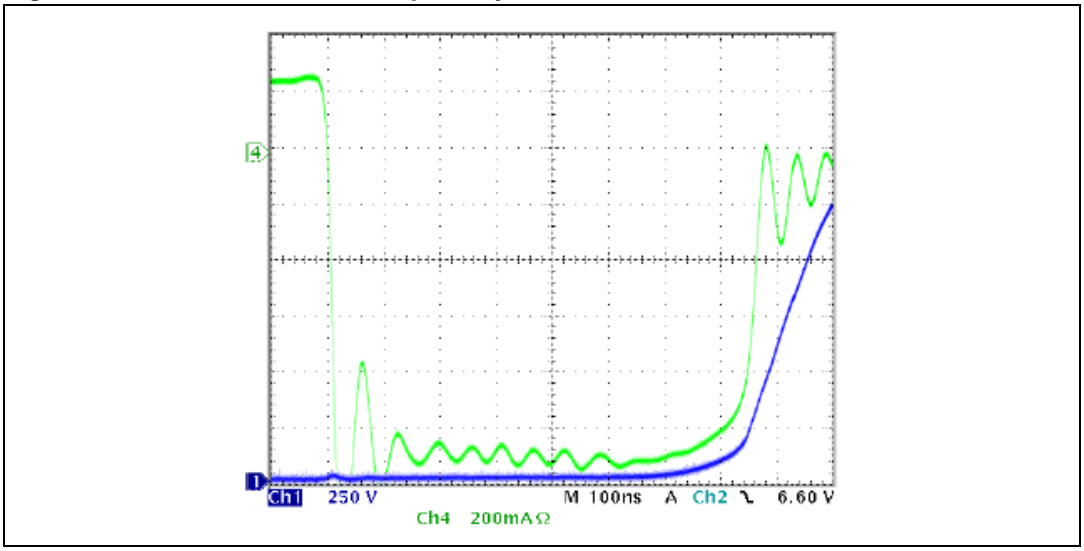


Figure 18. shows the part of the base current waveform that corresponds to the storage time. Collector voltage is also represented. The Collector voltage rise indicates where storage finishes and the current fall time begins.

Figure 18. Detailed view of the primary switch base current



Note: Channel 4 shows the base current (green) and channel 1 shows the collector voltage (blue).

Figure 19. highlights the proportional drive. It shows the collector current (channel 4 - green) and the base current (channel 3 - pink) at the same scale. Channel 1 (blue) is the collector voltage.

Figure 19. Proportional base current

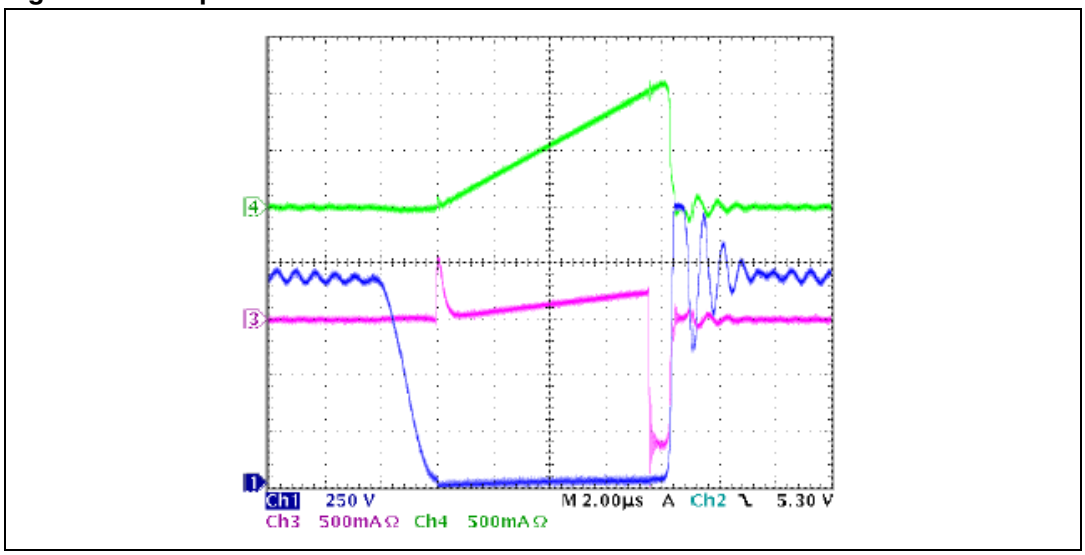


Figure 20. shows how the base current copies the collector current during the storage time and the current fall time. Channel 4 shows the collector current (green), channel 3 shows the base current (pink) and Channel 1 shows the collector voltage (blue).

Figure 20. Detailed proportional base and collector current

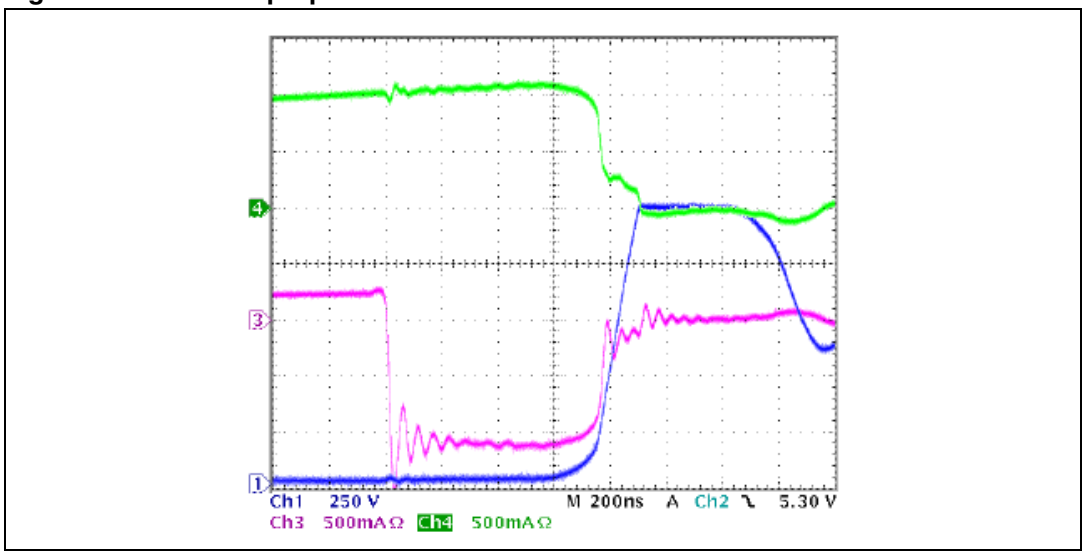


Table 7. shows the results of the case temperature measurement of the primary ESBT switch and secondary Schottky diode at a 25°C room temperature, for full power and two marginal input voltage values.

Table 7. Temperatures of the power switches at full load

Input voltage [VDC]	ESBT temperature [°C]	Diode D12 temperature [°C]
450	80.5	82
620	79.7	80.2

Note that the ESBT switch does not have any external heat sink attached to its case. The other most heating elements and sources of loss are the mains transformer and output capacitors. Even when the loss generated by these passive components is minimized by a suitable component selection and a good design, they are still significant overall converter loss sources.

3 Conclusion

This application note shows how to build a high-input voltage power supply operating in quasiresonant mode. The obtained efficiency is around the target value and can be further improved by introducing a synchronous rectifier in the place of the secondary diode. With its high speed, low conduction loss and low turn-on loss, the ESBT does not need a heatsink to be used as a primary switch.

As this power supply is designed for use as an auxiliary supply, and only part of the application is supplied from its input bulk capacitor, the EMI filter was not accommodated on the board and the power supply was not tested for EMC compliance.

4 References

- AN1699, “Efficient driving network for ESBT to reduce the dynamic V_{CESAT} and enhance the switching performances”
- AN1889, “ESBT STC03DE170 IN 3-PHASE AUXILIARY POWER SUPPLY”

5 Revision history

Table 8. Revision history

Date	Revision	Changes
Dec-2005	1	First issue
28-Nov-2006	2	- The document has been reformatted - *Table 2.* and *Figure 5.* modified

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